Mars Sample Return

A white paper for the decadal study

MEPAG Position Paper

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Note: This document is a draft that is being made available for comment by the Mars exploration community. Comments should be sent by Aug. 7, 2009 by e-mail to Lars Borg, Richard Mattingly, Karen Buxbaum (borg5@llnl.gov, Richard.Mattingly@jpl.nasa.gov, kbuxbaum@jpl.nasa.gov)

1 Are We Ready for Mars Sample Return (MSR)?

The scientific community has advocated sample return from Mars for decades (e.g., NRC, 1978; 1990a, 1990b, 1994; 1996; 2001), providing some of its most compelling arguments for the importance of sample return in reports of the Solar System Exploration Survey (SSES, 2003), the Committee on Astrobiology Strategy for the Exploration of Mars (NRC, 2007), MEPAG's Next Decade Science Analysis Group (MEPAG ND-SAG, 2008), and International Mars Architecture for the Return of Samples Working Group (iMARS, 2008). Each report, in its own terms, stresses that returned samples offer significant advantages over remote analysis of samples by landers and rovers.

In recent years, the wealth of *in situ* and remotely acquired data have significantly expanded our understanding of Mars and have shown that there are numerous promising candidate sites of astrobiological and geological interest for sample return. As anticipated by NASA's 1995 report *An Exobiological Strategy for Mars Exploration,* Mars has been extensively studied at global and regional scales, coupled with detailed local investigations to the point that the 2007 Astrobiology Strategy recommended that NASA should now "cache samples at every opportunity and return the most interesting collection as expeditiously as possible." The 2007 report also indicated that "identification of appropriate landing sites for detailed analysis … can be done with the data sets now available or imminently available from currently active missions." ND-SAG wrote that, "Global reconnaissance and surface observations have "followed the water" and revealed a geologically diverse martian crust that could have sustained near-surface habitable environments in the distant past. However, major questions about life, climate, and geology remain, and many of these require answers that only Earth-based state-of-the-art analyses of samples could provide."

While a substantial advanced technology development effort would be required, missions of the past decade have provided new capability and relevant experience, helping to make a sample return campaign a reality. Consistent with advice of the SSES of 2003, the Mars program has continued to build toward MSR with powerful landing site reconnaissance, heavy landing capability, etc. This MSR would not be a single mission, although "MSR" is often used to designate the flight elements that would lift the sample cache off Mars and return it to Earth. It is embedded, however, in a broad program of scientific exploration. While the advice to proceed with MSR has not yet become a reality, a solid foundation has been prepared and plans continue to be developed for a compelling sample return mission.

2 Why MSR?

Three special attributes make Mars a uniquely compelling target in planetary exploration as pointed out in iMARS, 2008:

- Mars is the most Earth-like planet in the Solar System, and while the first 700 million years of Earth's history are not preserved in its geologic record, this history is preserved on Mars. Since life got started on Earth during this period of time, much of the critical information about its origins and early evolution has been lost—the critical rocks are missing on our home planet. What could Mars tell us about the early evolution of water-rich terrestrial planets, and its relationship to the evolution of habitable environments?

- Of the various places of interest for evaluating whether or not life exists or has existed elsewhere in the universe, Mars is by far the most accessible. We can afford to send a regular series of missions, progressively building exploration technology and responding to the discoveries of previous missions. This accessibility allows us to address the life question in a systematic fashion.
- Mars is a potential target for eventual human exploration. Of our nearest planetary neighbors, Mars is the most compatible with crewed missions, and the scientific questions at Mars would most benefit from the attention of human explorers.

The unique value of returned samples has been described and defended in many arenas over the years. Because of the high cost of sample return, scientists have had to consider whether their objectives could alternatively be achieved either by *in situ* investigations or by study of the martian meteorites. Notwithstanding the price tag, the clear conclusion has consistently been that there is unique and compelling value of Mars samples returned to Earth for study.

In 2006, MEPAG identified 55 important future science investigations related to the exploration of Mars [MEPAG, 2006]. These investigations would depend on measurements from various spacecraft platforms using a variety of instruments, some of which do not yet exist for flight. The ND-SAG (2008) concluded that about half of the 55 MEPAG investigations could be addressed to one degree or another by MSR. In fact, they concluded that the return of carefully selected samples from a potentially habitable site would make the most progress towards the entire list. Moreover, given the scope of what is realistically achievable via *in situ* exploration technology, many of these investigations cannot be meaningfully advanced without returned samples.

Several of the high-priority investigations would involve sample preparation procedures that would be too complicated for *in situ* missions. Other investigations would require extensive heating to high temperatures (>1000C), complex extractions followed by chemistry on the extracts to produce derivatives for organic analysis, freeze-drying, etc. Flight instruments cannot match the adaptability, array of sample preparation procedures, and micro-analytical capability of Earth-based laboratories (Gooding et al., 1989). For example, analyses conducted at the submicron scale were crucial for investigating the ALH84001 meteorite, and they are essential for elucidating many of the complex geological, and potential biological, processes that have occurred on Mars. Furthermore, spacecraft instrumentation simply cannot perform certain critical measurements, such as, precise radiometric age dating, sophisticated stable isotopic analyses, and comprehensive life-detection experiments that are central to current scientific questions regarding Mars. If returned samples yield unexpected findings, subsequent laboratory-based investigations could be adapted accordingly. Adaptations based on new inputs (discoveries) are much more difficult, if not impossible, for landed or orbital missions that have fixed architectures. Moreover, portions of returned samples could be archived for study by future generations of investigators using ever more powerful instrumentation. Thus, returned Mars samples would have the great potential to significantly expand our knowledge of the planet and potentially answer some of our most fundamental questions.

Mars meteorites are useful for some, but not all questions. All of the approximately 40 known meteorites are relatively fresh igneous rocks, derived from either thick basalt flows or sub-volcanic intrusive rock. None are sedimentary rocks, hydrothermally altered rocks, and evolved igneous rocks and consequently cannot be used to address several important scientific questions. Finally, without knowledge of their origin and their context as samples, their scientific value is greatly reduced.

The most recent scientific observations from Mars have extended the rationale for the return of Mars samples. Observations of possibly recent flow of water in gullies and active release of plumes of methane into the atmosphere provide strong new evidence for the presence of life-sustaining resources on Mars. However, detection of discrete emissions of methane are difficult to reconcile with our current understanding of the oxidizing capacity of an atmosphere bathed in UV radiation and charged with fine-dust particles. This underscores the fact that there are fundamental aspects of the carbon cycle on Mars that we have yet to understand with remote, orbiting, or landed scientific instruments, adding to the rationale for returning samples of Mars to highly flexible and adaptable Earth-based laboratories.

3 Science Objectives

Eleven candidate scientific objectives for MSR were recently identified by MEPAG ND-SAG (2008) and incorporated into the iMARS analysis and report (2008). Ten of the objectives, which are listed below, have the potential to be addressed in the return of samples from a single well-chosen site, with the eleventh requiring ice samples probably from a separate site. Even without the ice-related objective, the choice of landing site would play a critical role in determining the degree to which these remaining ten objectives could be pursued. But the broad consensus is that the ability to address ten objectives would make an enormous contribution to the high-level goals for Mars exploration. The ND-MSR-SAG formulated a series high-level objectives based on the goals outlined by MEPAG (2006) that would *require* samples from Mars. Note that these are some of the most fundamental questions regarding Mars and planetary science that remain unanswered. Ten of these science objectives are summarized below:

1. Determine the chemical, mineralogical, and isotopic composition of the crustal reservoirs of carbon, nitrogen, sulfur, and other elements with which they have interacted, and characterize carbon-, nitrogen-, and sulfur-bearing phases down to submicron spatial scales, in order to document processes that could sustain habitable environments on Mars, both today and in the past.
2. Assess the evidence for prebiotic processes, past life, and/or extant life on Mars by characterizing the signatures of these phenomena in the form of structure/morphology, biominerals, organic molecular and isotopic compositions, and other evidence within their geologic contexts.
3. Interpret the conditions of martian water-rock interactions through the study of their mineral products.

4. Constrain the absolute ages of major martian crustal geologic processes, including sedimentation, diagenesis, volcanism/plutonism, regolith formation, hydrothermal alteration, weathering, and cratering.
5. Understand paleo-environments and the history of near-surface water on Mars by characterizing the clastic and chemical components, depositional processes, and post-depositional histories of sedimentary sequences.
6. Constrain the mechanism and timing of planetary accretion, differentiation, and the subsequent evolution of the martian crust, mantle, and core.
7. Determine how the martian regolith was formed and modified, and how and why it differs from place to place.
8. Characterize the risks to future human explorers in the areas of biohazards, material toxicity, and dust/granular materials and contribute to the assessment of potential *in situ* resources to aid in establishing a human presence on Mars.
9. For the present-day martian surface and accessible shallow subsurface environments, determine the preservation potential for the chemical signatures of extant life and prebiotic chemistry by evaluating the state of oxidation as a function of depth, permeability, and other factors.
10. Interpret the initial composition of the martian atmosphere, the rates and processes of atmospheric loss/gain over geologic time, and the rates and processes of atmospheric exchange with surface condensed species.

There is a strong connection between the highest priority science objectives, the range of lithologies that would have to be sampled—sedimentary, hydrothermal, and igneous—and landing site selection. The coupling of the objectives to the diverse lithologies arises from the variety of significant processes (e.g., igneous, sedimentary, hydrothermal, aqueous alteration, etc.) that played key roles in the formation of the martian crust and atmosphere. Each process creates materials that differ in significant ways and that collectively could be used to interpret geological events. There might not be any single landing site on Mars that could produce all of the samples necessary to support all of the key objectives. But the extent of what could be achieved at a single landing site would depend on such things as the rover's mobility, its ability to do scientific sample selection, and context documentation. Fortunately, remote sensing and *in situ* investigation have revealed many diverse sites where materials would be accessible in a single rover mission. The landing site selection process would, therefore, be an essential part of the scientific planning for sample return. Based on analysis of representative mission sequence timelines, suites of about 5 to 8 samples represent a reasonable compromise between scientific needs and mission constraints for MSR samples. The following kinds of sample suites are under consideration and are discussed more fully in the ND-SAG report.

The collection of Mars samples would be most useful if samples are collected as sample suites that represent the diversity of the products of various planetary processes. Nine individual sample suites would be required to address all of the scientific objectives outlined in the MEPAG Goals document (2006). These include: (1) sedimentary rocks, (2) hydrothermal deposited rocks, (3) low temperature altered rocks, (4) Igneous rocks, (5) a depth resolved sample suite, (6) regolith samples, (7) dust, (8) ice, and (9) atmosphere. These sample types are linked to the specific scientific objectives discussed in Table 1.

TABLE 1. Linkage of scientific objective to specific sample types necessary to meet objective

Objective Nickname	Sample Type									
	Objective #	Sedimentary Rocks	Hydrothermal Rocks	Low Temp. Altered Rocks	Igneous Rocks	Depth Resolved Rocks	Regolith	Dust	Ice	Atmosphere
Habitable Environments	1	H	H	L	L	M	L		L	L
Pre-biotic Processes, Past and Extant Life	2	H	H	L		M			M	L
Water/Rock Interactions	3	H	H	H			M			
Geochronology	4	M	M		H					
History of Surface water (Sedimentary Record)	5	H		M						
Planetary Evolution	6				H		M			M
Regolith Formation	7					M	H	M		
Surface Oxidation	8			H		H	M	M		
Atmosphere	9	M	M		M					H
Polar Deposits	10							M	H	M

Priorities expressed as H = high, M = medium, L = low.

Any mission architecture decision should take into consideration the number and priority of scientific objectives that could be met with a single set of samples or sample suites. Clearly, the types of samples collected must be further refined in light of specific mission objectives for specific sites. But a single mission, returning a collection of carefully selected samples, would greatly facilitate our understanding of the planet, even though it could not address all scientific questions.

Although the return of samples from the surface of Mars would have tremendous scientific potential, it would require multiple mission elements, including the first ascent and return from another planetary body. This would be an expensive enterprise requiring that difficult choices be made to balance scientific yield and cost. Within this context, the issues that must be balanced include: (1) sample size, (2) number of samples, (3) sample encapsulation, (4) diversity of the returned collection (5) *in situ* measurements for sample selection and documentation of field context, (6) surface operations, (7) sample acquisition system, (8) sample temperature, (9) planetary protection, and (10) contamination control.

It is clear from the analyses of several groups (e.g., MEPAG ND-SAG, CAPTEM) that many critical scientific objectives for Mars could be addressed only through the study of samples returned to Earth. Furthermore, a decade of detailed orbital, lander, and rover-based studies has greatly facilitated our ability to extrapolate the results from sample-based studies and place them within a geologic context. Though much remains to be done, this capability has been achieved while making significant technical progress in terms of instrumentation and robotic tools needed to select appropriate samples and characterize their surroundings as well as development of a landing system capable of landing a sample return vehicle.

4 Planetary Protection and Sample Purity

It has long been recognized that a central task of planetary protection is the protection of the Earth's biosphere from potentially harmful contamination. Assuming a sample is returned from Mars, it would be contained until completion of a comprehensive test protocol to assess sample safety. This phase of sample return would require creation of a specially designed sample receiving facility (SRF). The need to preserve sample purity while maintaining containment would continue throughout the sample assessment phase.

To assure maximum scientific value of the returned samples for decades of work to be performed in Earth laboratories, organic and inorganic contamination control measures would be needed from the time of sample collection through the years of curation and study. Design teams should analyze these challenges early in formulation of flight missions, which would acquire and return the samples, and through development of the SRF.

5 Mission Implementation

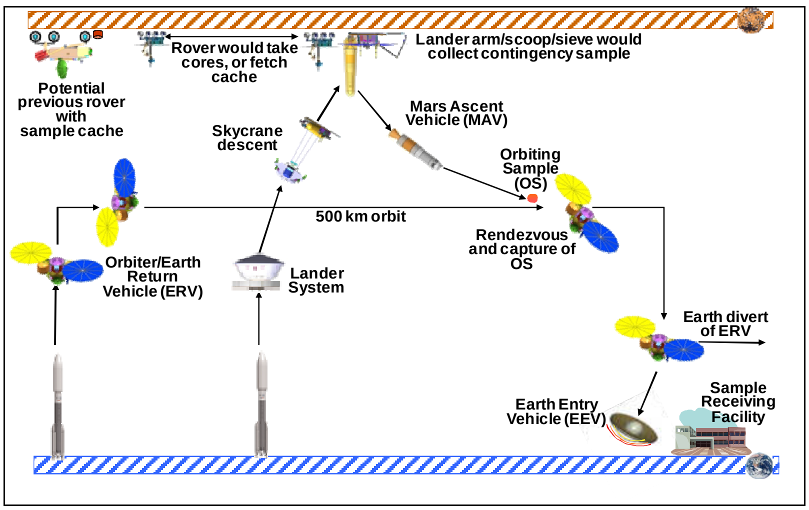

Figure 1. Generic MSR Mission Scenario

Nominally, the orbiter would be sent one opportunity (26 months) prior to lander to spread cost. The lander could go first if telecomm infrastructure already exists at Mars. The orbiter could return two EEV's if two landers were sent to different locations. Sample collection and caching by a prior mission is being studied and considered as a way to reduce program risk.

MSR would require a lander to acquire and/or retrieve samples and deliver them to Mars orbit via a Mars ascent vehicle (MAV) and an orbiter to capture that sample container, return to Earth, and deliver the sample to the surface via an Earth entry vehicle (EEV). The lander, launched on a medium-class vehicle, would use the Mars Science Laboratory (MSL) delivery system to navigate to Mars, perform a direct entry, and soft-land the pallet lander. With most mission opportunities in the 3rd decade having similar conditions to MSL's in 2011, the lander mass would be constrained to roughly the MSL rover mass, in this case supporting the MAV and a sampling rover, or alternatively a 100kg-class fetch rover to retrieve a cache from a prior mission. Sample acquisition would take close to a year by a MER-size rover, with enhanced traverse capability, to collect and encapsulate cores, guided by a small suite of instruments. Nominally 20 cores would be taken across four locations, while regolith and atmosphere would be taken at the lander (which also could collect a contingency sample as backup). Sample collection and caching by a prior mission would be a very promising approach to reduce program risk. This prior mission would perform the sample acquisition as mentioned above, and a fetch rover would retrieve the sample for return. The use of a fetch rover would also provide substantial mass margin for the lander system. Hand-off of the sample container (OS) from the lander to the orbiter would be carefully architected to meet planetary protection requirements. The MAV would nominally utilize existing solid-motor technology. The orbiter element, nominally sent one opportunity before the lander (to provide telecomm infrastructure), would also be launched on a medium-class vehicle. Aerobraking at Mars would be necessary to reduce the propellant requirements for this fuel-intensive vehicle. The orbiter would detect, rendezvous with, and capture the OS in low Mars orbit. The EEV, carrying the OS, would be returned to Earth like Genesis and Stardust, though the baseline design would not require a parachute. An additional significant element of a sample return campaign would be the Mars Returned Sample Handling (MRSH) ground segment which would include landing site operations, Earth surface transportation, an SRF (for quarantine and sample safety analysis) and curation. This proposed mission architecture is compatible with foreign collaboration, confirmed by a recent international study (iMARS 2008). Technology needs for a potential MSR are described in a separate Mars Technology White Paper. Technology development, planning for the SRF, and the NEPA process would all need to start at least eight years before the first launch. The overall cost for the Mars sample return campaign, including technology development, mission development, and sample facilities, is estimated at $4-8B in FY'09 funds.

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